on the postoperative course. In particular, the follow-up period in group S patients was relatively short inasmuch as they were growing; therefore, the inference regarding freedom from conduit obstruction and the need for reoperation in relation to outgrowth is uncertain. Further, a long-term follow-up study is essential.

In conclusion, we evaluated the technical feasibility of ECFP in patients weighing less than 10 kg. In terms of mortality and midterm results, the outcome of ECFP was acceptable in patients who weighed less than 10 kg. Currently, it may not be possible to consider ECFP as the standard procedure in patients weighing less than 10 kg. However, the procedure may be feasible in patients who, for instance, have severe cyanosis owing to pulmonary arteriovenous malformation. Further studies are required to assess the late hemodynamics of patients with small conduits when they achieve full somatic growth and the long-term outcome of these small conduits.

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Discussion

Dr Ed Petrossian *(Madera, Calif)*. Dr Ikai, I enjoyed your presentation. I will make a comment on the paper inasmuch as I believe it is an important subject, and I have 3 questions for you. The comment will be primarily focused on the issue of putting in small conduits in small patients.

In this study, you and your colleagues have shown that the ECFP can be performed with excellent perioperative and midterm outcomes in patients less than 2 years of age and less than 10 kg in weight. At a median follow-up time of 29 months, there were no thromboembolic events and none of the patients required conduit replacement owing to obstruction. I believe this is an important and timely paper because it brings into light the concerns and controversies about the timing of this operation with respect to age, weight, and the related issue of conduit size. Regarding the choice of conduit size, this decision is influenced by two competing factors. The first is the desire to insert a large conduit to avoid growth-related obstruction. Ideally, the conduit should match or slightly exceed the size of an average adult IVC at the level of the diaphragm. The second is the desire to avoid extremes of IVC–conduit mismatch. Significant mismatch can lead to turbulence, energy loss, stasis, and thrombosis. Information on the average size of the adult IVC at the level of the diaphragm is limited. Most studies instead report the size of the infrahepatic or most commonly the infrarenal IVC. Accuracy of the studies is affected by the fact that the IVC is an extremely compliant vessel so that its diameter and shape vary greatly with a number of factors, including patient body position, volume status, systemic venous pressure, phase of respiration, and to a lesser extent phase of the cardiac cycle. In adults, the size of the IVC does not correlate with age, height, weight, or body surface area. Therefore, prediction of a patient's future IVC diameter based on projections of the patient's future height, weight, or body surface area as an adult may be inaccurate.

The most consistent finding of the IVC diameter is that it correlates well with right-sided systemic venous pressures. Patients with elevated pressures have been shown to have significantly dilated IVCs. It therefore follows that an adult patient with a Fontan circulation and an inherently elevated systemic venous pressure will be expected to have a dilated IVC. The available data on IVC diameter

based on angiography, computed tomographic scan, and echocardiographic studies suggest that the average normal IVC diameter ranges from 20 to 28 mm with significant interstudy variability. In patients with elevated systemic venous pressures, the average diameter is about 30 mm. These data suggest that most conduits, especially those less than 18 or 20 mm, eventually will need to be replaced. It appears, therefore, that a protocol of using small conduits in patients less than 10 kg in weight will likely lead to significant conduit obstruction and the need for early reoperation. One option, of course, is to routinely use 20-mm conduits in these small patients. Although you did not report any case of thromboembolism, we believe that insertion of markedly oversized conduits is not an optimal solution either, inasmuch as it can cause significant IVC–conduit size mismatch and related complications.

I have 3 questions for you. First, what size mismatch between the IVC and the conduit are you comfortable with at the time of the operation? In other words, when you are trying to decide what size conduit to insert at the time of the operation, how much larger can the conduit be compared with the size of the IVC?

Dr Ikai. Thank you, Dr Petrossian, for your comments and the question. Size mismatch between the IVC and the conduit may not be so big an issue. We have not measured the size of the IVC during the operation because we can cut the IVC not on the IVC itself. Maybe sometimes we can make the incision line to the right atrium and maybe the IVC tissue has included some right atrial tissue. That means that these tissues are very flexible and sometimes we can put a much larger conduit on that. Maybe a problem has happened with size mismatch between the pulmonary artery to the conduit. Another big issue is if we insert too large a conduit, pulmonary vein obstruction may result. We think that in a baby weighing less than 10 kg, an18 mm in diameter conduit is suitable. In a baby less than 20 kg, maybe a 20 mm in diameter conduit is suitable.

Dr Petrossian. I agree with you. We also use a cuff of atrium to anastomose to the conduit and not the IVC itself so that we can put in a larger conduit, and the conduit is almost always larger than the IVC; however, there is a limit to that. In our experience, and I think this is corroborated by others, we try to avoid upsizing the conduit by more than 25% compared with the size of the IVC to avoid a sudden change in vessel caliber going from the IVC to the conduit. This discrepancy has been demonstrated to cause a lot of turbulence, energy loss, stasis, and thrombosis.

My second question is, since your patients less than 10 kg are at risk for outgrowing their conduits, how do you plan on monitoring them? In other words, what diagnostic modalities do you use to look for conduit obstruction as these patients grow?

Dr Ikai. I showed the postoperative angiogram in the presentation. We routinely perform angiography a year after the operation. At that time, if the conduit shows some obstruction, it may be a problem, but so far we have not seen any obstruction on the angiogram. If the patient needs more follow-up, we use a computed tomographic angiogram or a magnetic resonance angiogram because they are less invasive measures.

Dr Petrossian. In our experience with more than 360 Fontan patients, we have been primarily monitoring them with echocardiograms, but I agree with you that as these patients grow and become more at risk for conduit obstruction, more accurate imaging modalities are going to be necessary. Magnetic resonance imaging, computed tomography, and probably also cardiac catheterization may be needed to measure the gradient across these conduits.

My third and last question is, what will be your criteria for reoperation for conduit obstruction in asymptomatic patients? We all agree that symptomatic patients will need conduit replacement, but at what point and with what diagnostic findings will you be comfortable with replacing a conduit in an asymptomatic patient?

Dr Ikai. It is very difficult to change the conduit in an asymptomatic patient. However, if there is a pressure gradient between the IVC and the conduit at catheterization, we may have to do the operation. During catheterization, with the patient in the resting position, the data, the pressure number, may not be accurate, so we probably will have to do an exercise test for these patients and get some exercise tolerance. If these numbers become low, that may indicate that the conduit should be changed.

Dr Petrossian. I agree that exercise testing may be one way to determine when it is time for conduit replacement. Imaging modalities may not be sufficient. These IVCs will eventually dilate because they are very compliant vessels. The fact that they become very large does not necessarily mean that they are obstructed. In addition, collaterals will develop, just as with the SVC, in patients with bidirectional Glenn shunts, so it will be difficult to figure out when it is time to replace the conduit. However, I think if at cardiac catheterization there is any gradient, even a small amount of gradient between the conduit and a dilated IVC in combination with an abnormal exercise test, then it will be time to proceed with conduit replacement even if the patient is asymptomatic.

Dr Ikai. In terms of reoperation, when we started this strategy, we were still thinking about this Fontan procedure as a palliative procedure because we did not have any long-term result with this small conduit. Now, because of the good result of the Fontan conversion from the classic Fontan to the total cavopulmonary connection, we think the operation itself is not so risky, especially in a patient who has an established Fontan circulation.

Dr Petrossian. I certainly I agree with that. When the patients return to have the conduit replaced, it is not as big an operation or as risky as the first primary Fontan.

Dr Winfield Wells *(Los Angeles, Calif).* My question is pretty simple. Why do this? What are the advantages? Your 2 groups came out the same. The saturations are the same in the longer-term follow-up. They seemed to have the same saturations when you did them, so why not wait? What are the advantages of doing this operation in a patient weighing less than 10 kg?

Dr Ikai. We believe that the final goal of the Fontan operation is elimination of cyanosis, and in these 2 groups the big difference is not only the body weight but also the age. We did this operation at around a year of age. If we wait until patients become 15 kg, we may have to wait until the baby becomes 2 or 3 years old. Waiting these 1 or 2 years may not be good for the patient. In these 2 years the patient's activity is increasing. Maybe the child starts walking and running. This quality we think is very important. We want to eliminate cyanosis. That is our reason to do this operation.

Dr Wells. Do you have any evidence for that?

Dr Ikai. We have not published yet, but when we do this operation at the younger age, some children catch up soon. This is another reason to do this operation early.